HUMAN ERROR, TECHNOLOGY, AND PATIENT SAFETY: GUIDELINES FOR THE IMPLEMENTATION OF NEW TECHNOLOGY INTO MEDICAL ENVIRONMENTS

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Medical environments in particular present a number of challenges for human-machine interaction. Users are the 'sharp end' (Bogner, 1994) and often get the blame for errors involving technology. Unfortunately the problem is usually not that simple. Often, the cause can be traced back to the organization and their practices for implementing technological devices into a workplace that is, even at its best, complex and dangerous. Problems ranging from inadequate or one-dimensional training to a lack of organizational support can lead to errors that compromise patient safety. Therefore, we have developed a set of guidelines based on multidiscipline literature reviews (e.g., human factors, I/O psychology, training, human-computer interaction) to improve safety following the implementation of new technology into medical environments on multiple levels (i.e., organization, departments, teams, individual). Factors such as training, usability, and organizational support are addressed.

Introduction

In 1988, crewmembers of the U.S.S. Vincennes erroneously shot down an Iran airbus, killing 290 civilians (Klein, 1989). In the final report, investigator Fogarty (1988) cited human error as the causal factor. However, Klein (1989) and others expanded on the findings and said citing human error alone was too simplistic. Rather, there were certain factors reported by Fogarty that could not be filed under the heading of human error. For example, the technology used by the crewmembers was unfamiliar to them (namely the displays) and may have led to crewmembers believing the aircraft was descending rather than ascending. Additionally, former Navy decision aid technology was often described as ambiguous in identifying the position and intentions of aircraft. So who or what is to blame? This example shows that more than just human error can lead to an accident when humans in complex environments rely on technology.

Technology is everywhere in our modern society. In fact, it is difficult to go about the normal business of our day without encountering technology; some may say it's impossible. While technology makes our lives easier and, often times safer, technology can lead to confusion, frustration, and error. Technology in the workplace is often credited with increasing safety, particularly within high-consequence environments (e.g., medical, military, aviation), where technology can be seen as a cure-all for safety issues. However, while the introduction of new technology can have a positive impact on safety, human error caused by the interaction with new systems can lead to an increased risk when technology is introduced into complex, dynamic situations. Often, blame is placed on the users as they are the most salient component in a given scenario, what Bogner (1994) calls the 'sharp end'. But errors within complex environments are rarely that simple.

Within the medical community, safety is a particularly important issue, as it has been suggested that up to 98,000 people die each year as a result of medical errors (IOM, 1999). In the much publicized report *To Err is Human,* the Institute of Medicine (IOM) stressed the propensity for error in medical domains, which can easily be classified as high consequence environments. As a result, leaders in the medical community have become increasingly interested in mechanisms and policies to improve patient safety. For example, many hospitals are implementing automated dispensing units (ADUs) that store, dispense, and track medications. While these interventions have obvious safety benefits, often times the implementation can be more difficult or confusing for the actual users. Therefore, the purpose of the current paper is two-fold. First, we will briefly review the human factors literature regarding human error and technology. Second, we will outline guidelines that can help organizations minimize errors when implementing new technology into high consequence domains, such as hospitals and health care institutions. Although the focus of this paper is on the medical community, the guidelines presented are likely relevant in other high consequence domains as well.

Human Error Literature

Like other high consequence environments, the medical domain is inherently complex and dynamic, which makes it particularly prone to errors. In addition to their complexity, medical, aviation, and military environments also have in common their propensity for relying on new technology. However, the definition of 'error' is vague within this domain (Wears, 2000). In fact many errors go undetected without consequence or are easily and quickly remedied. Fordyce et al. (2003) found errors within an emergency department were relatively common (i.e., almost 1 in 5 patients), but the adverse consequences that resulted from errors were extremely rare (i.e., almost 1 in 300). This would lend itself to the idea that these low consequence errors should be treated differently than the more severe errors that have obvious, detrimental consequences. As a result, this section will borrow from the human factors literature to better define what constitutes errors and differentiate between slips/lapses and mistakes. This may help better clarify the scope of interest in human error within the medical community. In addition, errors specific to system use will also be examined.

Reason (1990) defined *error* as "a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome…" (p. 9). Reason further delineated two types of errors: 1) slips and lapses; and 2) mistakes. Slips and lapses are a category of errors that, regardless of whether the plan to execute them was adequate, led to some failure in the execution or storage stage of an action. *Mistakes*, however, refer to deficiencies in the judgment or planning stages of an action, are less accessible to observation, and often more complex (Reason, 1990; Woods, 1984). Because of this, mistakes are often the source of the adverse consequences discussed earlier and the error of most interest for the current study. Technology in general often has safety nets built in to correct or catch slips or memory lapses (e.g., the O2/N2 ratio limiter that prevents the accidental administration of a dangerous combination of gases by an anesthesiologist; Felciano, 1995), while mistakes often occur without detection until it is too late.

Beyond the observable, we must also be aware of cognitive elements to human error. Rasmussen and Jensen (1974) proposed the skill-rule-knowledge framework, whose three levels of performance (i.e., skill, rule, and knowledge) correspond with three decreasing levels of familiarity (i.e., automated, familiar, and novel) with the task and its environment. Based on this model, mistakes can be further differentiated within Reasons' taxonomy (1990). Reason asserts that mistakes can be either rule-based or knowledge-based. Furthermore, this taxonomy classifies slips/lapses as skill-based slips. The relationship between Reason's errors, Rasmussen's performance levels, and GEMS is illustrated in Table 1.

Errors and System Design

One additional classification of errors must be discussed before we move on. The use of technology in high consequence environments (e.g., nuclear power plants) has precipitated additional types of errors brought about by some high profile disasters (e.g., Chernobyl; Three-Mile-Island) relating directly to system design (Rasmussen & Pedersen, 1984). *Active errors* are identified as those errors whose effects are felt immediately. *Latent errors,* on the other hand, refer to errors whose consequences may lay dormant for a period of time and only show themselves when they combine with other elements to breach a system.

What Can Be Done?

While there are a number of factors that can influence the occurrence of human error when interacting with new technology, there are three variables from a human-centered approach that have been extremely beneficial in a wide range of complex, dynamic environments (e.g., aviation, military, nuclear power, transportation). First of all, comprehensive training is extremely important with the introduction of new technology (Hancock, 2000; Oser, Cannon-Bowers, Salas, & Dwyer, 1999). Second, the usability of the system must be acceptable, especially when used in high workload or high stress environments. Third, the technology, as well as the practice and method of using the technology, must have organizational support to reduce errors and increase safety. The following sections discuss the importance of these three factors in the implementation of new technology into complex domains, with respect to what is known about human error.

Training

Traditionally, the medical domain has focused on skill-based training (e.g., how to start an IV; how to conduct a patient interview; Smith, Lyles, Mettler et al., 1998). While skills are vital in such an outcome-focused field where the goal is to save lives, there is more to performance than simply learning the steps and procedures. When interacting with new technology, users need competencies beyond just the know how to operate the system. Training literature cites the need to train on multiple levels, focusing on not just the skills, but on the knowledge and attitudes of the users (Coovert, Salas, & Ramakrishna, 1992; Kraiger, Ford, & Salas, 1993; Salas & Cannon-Bowers, 2001). Training should be designed to focus on the systematic acquisition of knowledge (i.e., what we *think*), skills (i.e., what we *do*), and attitudes (i.e., what we *feel*) (KSAs) specific to high consequence environments that lead to improved performance in a particular setting (Salas, Dickenson, Converse, & Tannenbaum, 1992). As it is likely the case that users of technology in high consequence environments will be facing situations requiring that they be adaptive, the need to know more than just how to conduct particular tasks is necessary. Rather users must be trained with the knowledge needed to understand why the system operates in a particular way and what can be done to incorporate the system into the changing environment.

Especially regarding new technology, many organizations stress training on the new device, but focus only on the procedural knowledge necessary to operate it under normal work conditions. While this may be sufficient for such mundane technology-centered tasks as word processing where consequences are less serious, more complicated, high risk tasks are rarely conducted under "normal work conditions". Often times, professionals in health care are asked to perform under time pressure, high workload, or while numerous distractions (e.g., buzzers and warnings) are competing for resources. This makes the need for comprehensive training even more inherent.

GUIDELINE 1: Train for adaptive organizations…incorporate the necessary knowledge, skills, and attitudes.

Some medical professionals have put forth the idea that they must have experienced failure in order to know how to prevent it, referring, of course, to the less harmful slips or lapses. It seems that is beginning to occur to some that "In an odd way, it seems that failure-free performance requires experience with failure" (Wears, 2003, p. 336). As failures are not an accepted practice in any organization, when a failure does occur it is important that the organization as a whole learn from it. This is an idea that has been embraced in high consequence environments (e.g., aviation). Humans will make errors. The trick is to learn what we can from them and minimize the consequences of future errors. One way that organizations can learn from errors is to incorporate areas of concern into training. Specifically, simulation-based training (SBT), also called scenario based training or event-based training (EBAT), can be a useful tool to allow health care professionals to gain this experience and practice. SBT uses scenarios that contain embedded trigger events designed to elicit specific behaviors (Fowlkes, Dwyer, Oser, & Salas, 1998). These scenarios can be designed by subject matter experts (SMEs) to simulate emergency situations that will likely bring about errors without the meaningful consequences experienced in the medical domain. These opportunities for errors will give trainees experience and will help them make better decisions when faced with real world consequences. The aviation (Salas, Fowlkes, Stout, Milanovich, & Prince, 1999) and military (Cannon-Bowers, Burns, Salas, & Pruitt, 1998) domains have used this technique for decades as a way to increase knowledge, skills, and attitudes (KSAs) of individuals and teams without the casualties that typically come as a result of errors within their environments. This method also allows trainees to become aware of what will occur based on their actions and allow them to try out possible solutions to the errors made.

When consequences of errors may cost someone their life, it is difficult to allow new technology users to learn from their mistakes. However, simulations allow for consequence free mistakes. For example, SBT provides the opportunity for an aircrew to walk away from the crash of a simulated flight or a soldier to receive feedback on what led to him erroneously fire on a friendly tank on a simulated battlefield without any danger to fellow soldiers or himself.

Relating this intervention to what we know about the different categories of human error, skill-based slips have been regarded as relatively minor and easy to detect and correct. The key to improving safety by reducing error is to give doctors, nurses, and pharmacists the tools to improve rule-based and knowledge-based performance. While SBT can provide a vehicle for skill-based training, it provides an ideal setting for rule-based and knowledge-based learning as well. Gaining experience in a simulated setting allows the medical professional to gain knowledge and learn methods for effectively handling novel or unexpected events through dealing with them firsthand. Ideally, SBT can help trainees form rules about these situations to better prepare them for real world settings. While it is impossible to design scenarios to cover every possible error, the overall experience should increase awareness and allow doctors and nurses to learn from their mistakes though feedback and practice.

GUIDELINE 2: Exploit simulation-based training…promoting learning from errors.

Simulation is an ideal environment for practice. But practice of the skills learned is not enough. In order to be effective, practice must be guided. Training for errors through guided practice allows trainees to not only experience the errors but to learn the consequences of these errors (Karl, O'Leary, & Martocchio, 1993; Lorenzet, Salas, & Tannenbaum, 2003). Trainees then receive feedback regarding their performance in order to improve learning and develop strategies for minimizing the consequences of these errors in the future. By simulating the use of new technology in complex situations, guiding trainees through errors while providing feedback and opportunities for practice, new technology can be more safely integrated into the medical environment.

GUIDELINE 3: Provide guided practice improves…build self-efficacy.

Usability

New technology is often developed to increase safety within complex and dynamic settings. However, designers must ensure that what they design is useful to the people who will be using it (Nielsen, 1993). It is important for those who design and, also, for those responsible for the implementation of new technology to remember that the device must be appropriate for both the purpose and the users. Users in the medical field will not be engineers, so designers must consider their knowledge base and needs. Furthermore, designers must consider the complexity of the environment within which the technology will be utilized. Often in design, the human is taken out of the equation and the design is developed without applying the principles of user-centered design. This can lead to new technology being misused or not even used at all. For example, when heads up displays were first introduced in cockpits, pilots often ignored them, because they had so many competing stimuli that they found them distracting. While the system may have performed the necessary functions, the designers did not factor in the environment. Therefore the system was not usable.

GUIDELINE 4: Employ a user-centered design approach…don't ignore the user!

Usability is typically measured by the five attributes that define it: 1) learnability, 2) efficiency, 3) memorability, 4) errors, and 5) satisfaction. For a more complete explanation of the usability attributes, see Table 2. While each of these attributes is important, some are more relevant to safety than others. Within the usability literature, errors refer to the users errors with a system. While this is obviously an important consideration within medical domains, especially with new technology, systems that cannot be easily learned and used efficiently can lead to mistakes. While memorability is more appropriate to systems used casually and would likely apply to specific examples within the medical field. The technology that users only use infrequently would need to be memorable so that users do not have to relearn the machine with each application.

GUIDELINE 5: Follow the design principles…don't ignore it!

While separate from the human error literature, usability is also concerned with safety. As is pointed out by Nielsen (1993) concerning usability error attributes, errors within systems include both active and latent errors as defined by Rasmussen and Pedersen (1984). He outlines two "other" types of errors:

"Other errors are more catastrophic in nature, either because they are not discovered by the user, leading to a faulty work product, or because they destroy the user's work, making them difficult to recover from. Such catastrophic errors should be counted separately from minor [slips/lapses] errors, and special efforts should be made to minimize their effects" (Nielsen, p. 33).

Ultimately, systems must be designed with the user in mind, both their needs and capabilities, in order to minimize errors. Safeguards (e.g., verification of dosage for ADUs) for both small and large errors are essential for ensuring safety, especially within the medical domain.

GUIDELINE 6: Reduce the chance of errors…design safeguards into systems.

Organizational Support

In the health care domain, medical professionals must constantly prioritize tasks in a high-pressure quick-paced environment. The introduction of any new device requires a level of commitment and time that is difficult to part with for everyone who must care for a growing population of elderly, sick, and infirm. As such, I/O Psychologists have long recognized the importance of organizational support (Stamper & Johlke, 2003). When implementing new technology into a work environment, the employees must feel that it has the complete support of management. In order for new technology to be embraced and utilized properly, users must know that the interruption to their hectic schedules is worth their time and has complete support from everyone at all levels of the organization. We would argue that within high consequence environments this support is even more important. The importance of organizational support when implementing technology cannot be understated. Furthermore, this support cannot merely be lip service. It is not enough for the organization to say that safety is important. Rather, organizations must support new technology in both words (e.g., policy changes) and deed (e.g., allowing work time for training).

GUIDELINE 7: Provide an organizational climate that supports the use of new technology…emphasize safety and its proper use.

Conclusion

Human users will make errors. That is a fact that must be accepted. However, there are many things that can be done to reduce these errors when new technology is implemented into an already complex, dynamic environment. There are many factors that influence whether or not the implementation of new technology is successful or not. While technology must serve its intended purpose in order to make work more efficient and help employees accomplish the appropriate tasks, many macro-level variables must be considered, especially within high consequence, complex domains. Training must be applied using SBT in order to encourage the acceptance of new technology with the least amount of errors. Systems must be developed and evaluated while considering usability principles. Lastly, the organization must actively support the implementation, use, and acceptance of technology that will improve patient safety through the reduction of errors. Conscientiousness when implementing new technology within the medical domain while considering the propensity and nature of human error can help reduce the consequences that come with the inevitable mistake.

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Table 1. Slips, Lapses, and Mistakes: Cognitive and Performance Levels

Cognitive Stage	**Performance Level**	**Error Type**	**Environment**
Planning	Knowledge-Based	K-B Mistakes	Novel situations, planning is done on-line
	Rule-Based	R-B Mistakes	Familiar problems, have stored rules for finding solutions
Storage	Skill-Based	Lapses	Environment is extremely familiar; have stored patterns of preprogrammed instructions
Execution	Skill-Based	Slips	

Table 2. Usability Attributes

Attribute	**What it Means…**
Learnability	Systems should be learnable, meaning that users should be able to quickly learn how to use a device so that they may utilize it sooner
Efficiency	Once the user has learned the system, the system should be efficient to use and promote a high level of productivity.
Memorability	While learnability focuses on novice users, memorability applies most directly to casual users. As a result, these users need to remember how to use it, since they do not use the system on a regular basis.
Errors	Ideally, users should make as few errors as possible. While errors are defined as any action that has an unintended consequence or does not achieve the intended goal, errors within usability evaluation are not so simple (Nielsen, 1993).
Satisfaction	Satisfaction, how pleasant the user finds the system to use, is often related more to nonwork or entertainment systems.